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US Army Corps of Engineers

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

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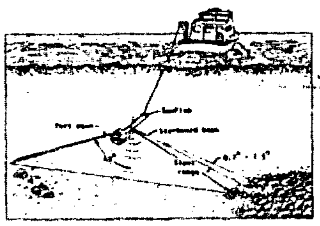
UNDERWATER INSPECTION OF COASTAL STRUCTURES USING COMMERCIALLY AVAILABLE SONARS

by

William M. Kucharski, James E. Clausner

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



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HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Connecting the side scan sonar towfish.

BOTTOM — Side scan sonar in operation.

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A general introduction to side scan sonar (SSS) and its uses in coastal engineering studies is given, including some operating rules-of-thumb and suggestions based on the authors' experience. There is also a section evaluating several systems currently on the market.

SSS is a valuable tool for coastal engineering, with uses likely to multiply as the technology and our experience with it improve. However, quantitative applications are limited. Information on structure slopes, condition of individual armor units, and percent of units displaced (to name a few examples) is not currently measurable in a repeatable, quantitative way. Nevertheless, the semiquantitative sonograph record can be very informative, particularly to someone who has developed a familiarity with the structure or feature being viewed from repeated SSS surveys. It is a safer, and in many cases, superior alternative to visual inspection by divers, especially in murky water.

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PREFACE

The work described in this report was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Coastal Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was carried out under Work Unit 32326, "Evaluation of Damage to Underwater Portions of Coastal Structures." Mr. Gary L. Howell (CEWES-CD-P), US Army Engineer Waterways Experiment Station (WES), Prototype Measurement and Analysis Branch (PMAB), was Principal Investigator. For the REMR Program, Problem Area Monitor is Mr. John H. Lockhart, Jr., HQUSACE.

REMR Program Manager is Mr. William F. McCleese (CEWES-SC-A), WES, Structures Laboratory, and Coastal Problem Area Leader is Mr. D. D. Davidson (CEWES-CW-R), WES, Coastal Engineering Research Center (CERC).

This report summarizes the experience gained by the authors in the course of their frequent use of sonar equipment for coastal engineering prototype studies and field testing of selected commercially available sonars for the purpose of assessing their usefulness in coastal applications during 1985 and 1987.

The preparation of this report was accomplished at CERC under general direction of Dr. James R. Houston, Chief, and Mr. Charles C. Calhoun, Jr., Assistant Chief, and under direct supervision of Mr. Thomas W. Richardson, Chief, Engineering Development Division, and Mr. J. Michael Hemsley, Acting Chief, PMAB. The original draft of the report was written by Messrs. William M. Kucharski, PMAB, and James E. Clausner, Coastal Structures and Evaluation Branch. Mr. Jonathan W. Lott, PMAB, revised and edited the subsequent drafts. Final editing before publication was by Ms. Gilda Miller, Visual Production Center, Information Technology Laboratory, WES.

COL Larry B. Fulton, EN, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots	1.852	kilometers per hour

UNDERWATER INSPECTION OF COASTAL STRUCTURES USING COMMERCIALLY AVAILABLE SONARS

PART I: INTRODUCTION

1. The purpose of this report is to give a general introduction to the side scan sonar (SSS) and its uses in coastal engineering studies, including some operating rules-of-thumb and suggestions based on the authors' experience. Several systems currently on the market are evaluated in paragraphs 35 through 44 as an aid to further research before purchasing equipment.

Current Coastal Engineering Applications

2. Perhaps the most important use of SSS for coastal engineering in terms of potential cost savings is early detection of damage and deterioration of underwater portions of coastal structures, thus permitting the responsible engineer to take action to minimize further degradation and to plan for repairs and rehabilitation with greater lead time. The ability of sonar to penetrate through waters too turbid or too dangerous for visual or optical inspection makes it the only effective means of surveying many coastal structures.

3. SSS has already proven useful in surveys of breakwaters, jetties, groins, port structures (bulkheads, pilings), and inland waterway facilities such as locks, dams, and hydroelectric works. It has proven especially effective in examining the toe portion of rubble structures for scour and displacement or armor units. Thus inspection, to qualitatively assess damage or simply to periodically check the condition of structures (including as-built surveys), is a proven and important application of SSS. Real-time display capability permits onsite decisions based on knowledge rather than guesses, and allows onsite improvements to the data collection plan in view of the results. Historically, SSS has been used primarily in reconnaissance and search applications such as pipeline and cable tracking, exploration, wreckage/debris location, navigational hazard mapping, and identification of bottom material (sand, rock, mud, etc.). Other current coastal engineering applications of the technology are found in dredging work (identification of

borrow and placement areas, determination of optimum orientation and spacing for bathymetric sounding lines), lost instrument search, and bottom evolution monitoring.

Background

4. SSS was originally developed as a tool to assist in the search and recovery of objects resting on the bottom, such as shipwrecks. Like echo-sounding fathometers to which SSS is related, the transducer emits a series of acoustic-frequency pulses (typically 50 to 500 kHz) traveling outward and encountering surfaces that transmit, absorb, or reflect the energy. The terminology "side scan" refers to the fact that the pulses are emitted laterally to the forward motion of the transducer; as such, the area of seabed scanned has a limited width and a length corresponding to the path length traveled by the transducer. Using the strength of the reflected energy and the time required for the return trip to the transducer, an image, typically a plan view of the bottom and objects resting on the bottom, is produced by the processor unit. If automatic correction for transducer position and forward speed is included in the processing software and if input from position-fixing equipment is fed to the unit, the resulting overlapping strip records can be pieced together to form a mosaic image which is an approximately accurate (scale) map of the bottom and its features. Additionally, the vertical dimensions of some features can be estimated from the length of shadows they cast, and other qualitative information can be inferred from the images, such as shape and relative position, of large and isolated objects.

PART II: SYSTEM CONFIGURATION

Sonar Components

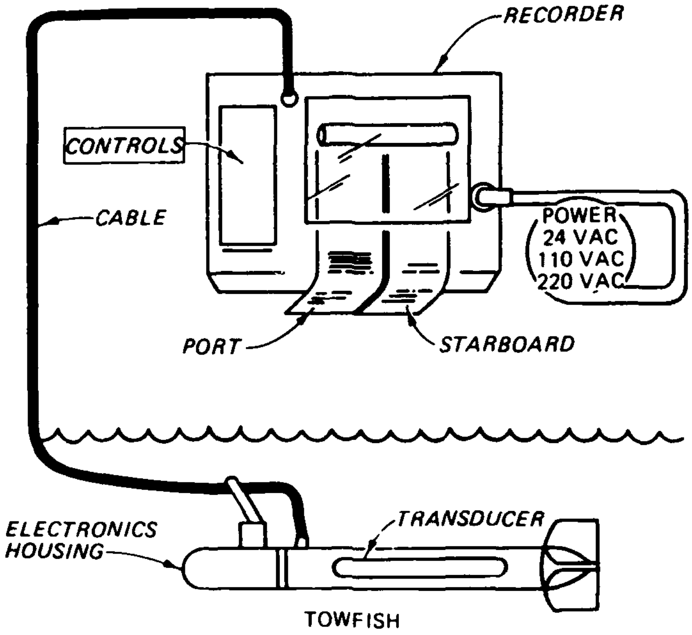
5. Components of an SSS system typically include, as a minimum: a towfish; a control/processing/display/recording/power unit; and a speed log (see Figure 1). The towfish is a streamlined body that houses the transducers, one on each side. The transfer of signals between the fish and the control unit occurs through an electrical cable that may serve a dual function as the towing cable. Forward speed of the transducer--used in automatic correction of along-track speed variation distortion of the record--can be measured by a separately towed speed log or by a speed log built into the towfish. The speed of the towing vessel can be input directly to the control unit.

6. Vertical elevation of the fish above the bottom--used for correction of across-track (slant-range) distortion--is determined using a directly downward-pointing separate acoustic transducer or is obtained from a downward-directed portion of the side-looking transducer's beam. Various optional and auxiliary equipment that might be added to the basic system include: data processing software/hardware modules for automatic corrections, image enhancement, digital recording, etc.; alternative display options (e.g. dry paper plotter, color CRT); separate DC power supply; annotation keyboard for placing marks and messages on the image; and position-fixing equipment.

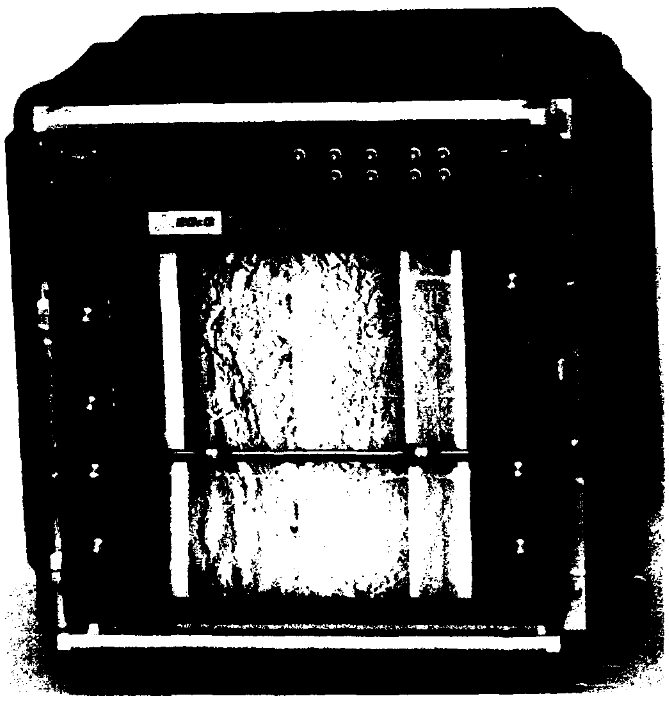
Platform Types and Means of Deployment

7. The type of problem to be studied, the site conditions, and the resources available will dictate the choice of platform. An advantage of the modern SSS systems is that they are small enough to be deployed in a variety of ways.

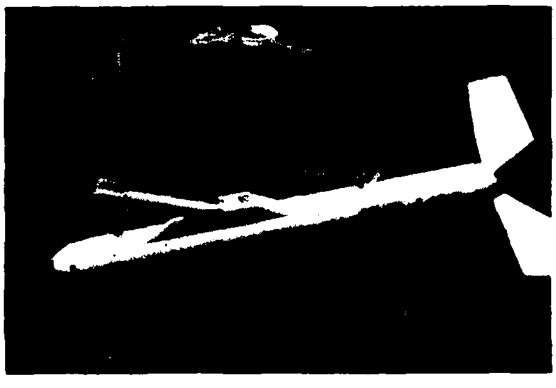
8. Most commonly, the SSS system will be deployed from a boat. In shallow water under calm conditions, a boat as small as an outboard-powered inflatable could be used (a further discussion of vessel requirements is found in paragraphs 12 through 27). In addition to the common deepwater deployment method where the fish is towed from the stern, deployment from the bow or the side of the boat near midships, possibly using a boom to extend the cable away from the hull, may be advantageous in both shallow and rough waters. In



a. Sketch of components



b. Control unit



c. Towfish

Figure 1. Side scan sonar components

addition to the obvious safety considerations, keeping the towfish away from the props and wake, a task more difficult in shallow waters where towing depth is limited, is desirable from a transducer performance standpoint.

9. Bow deployment is advantageous for vessel maneuvering and precise positioning of the fish relative to the object being surveyed. Midships deployment minimizes undesirable vertical heaving of the towfish in seas causing the boat to pitch; a boom extension may aid in getting the fish closer to the structure being scanned while maintaining a safe clearance for the hull. However, a disadvantage with midships deployment is that it may be difficult to avoid propeller noise that "blanks out" the record from the near-side transducer facing the hull.

10. Another option particularly well-suited to surveys of coastal structures, such as jetties and breakwaters, is to deploy the towfish from a truck-mounted crane, where the boom of the crane is extended out over the water and the truck is driven onto the structure itself. Other platform possibilities for coastal structure inspection include helicopters and remotely operated vehicle (ROV's).

Operating Personnel

11. Generally, it would be preferable to have one person working full-time at the control unit, observing the display and making adjustments as needed (note that with the modern digital image-correcting systems there is little need to regulate settings once a survey is underway), and a second person responsible for launching and positioning of the towfish. Under some conditions, the second person could have other responsibilities unrelated to the sonar equipment; with the lightweight, flexible tow cable designed for shallow tow depths, it is likely that the control unit operator could handle fish positioning as well. However, a minimum total boat crew of two is recommended.

PART III: OPERATIONS

12. As an introduction to the subject of operations, an idealized example of a typical coastal engineering SSS application is given first. Next, a more detailed discussion of limitations, problems, and recommended practices is presented, followed by a summary of operating rules of thumb. Since coastal engineering use of SSS is in its infancy, much remains to be learned. Any new problem should be approached with ingenuity and flexibility.

Idealized Example

13. A poststorm SSS survey of a rubble-mound breakwater on the open ocean side is needed. A Field Operating Agency (FOA) engineer is given the authority to purchase equipment and is free to plan timing of field work. Since the condition of the structure should be determined as quickly as possible before shifting sands cover the evidence, tide/current tables are quickly checked for time windows when there will be minimum currents and maximum depths. Arrangements are made to meet the FOA survey boat captain and crew at the marina to help install the new SSS equipment and to make a practice run of the structure. The FOA engineer arrives at the dock with an as-built plan of the breakwater (annotated over the years since construction as modifications and minor repairs were made) and the best available nautical charts. A manufacturer's representative instructs a hands-on lesson on operation of the new automatic speed- and slant range-correcting SSS equipment.

14. Fortunately, the survey boat is equipped with powerful engines and is stable and highly maneuverable. There is space to install the control unit in the covered bridge that, while sheltered from wind and spray, has good ventilation for the unit. This location also permits the operator to see the display and the position of the boat relative to the structure and to talk to the captain and crewman. In addition, there is room for the batteries to be used to guarantee an electrical noise-free power source, as well as the digital data recorder, position-fixing equipment, spare batteries, display paper rolls, and fuses. At the bow of the boat, there is a 15-ft boom that can be used to deploy the towfish and speed log. The boat also has ample open deck area to allow the crewman to work with the towfish, cable, and winch.

15. After the FOA engineer outlines the objectives of the survey with the captain, crewman, and manufacturer's representative, the representative gives a brief explanation of how an SSS works. The crewman and the representative load and set up the equipment while the engineer discusses the course to be navigated with the captain. As the captain begins a practice run on the course, the representative assists the engineer as he performs checks and makes initial settings on the control unit, then helps the crewman deploy the fish. During the practice run, SSS images are produced and various range and gain settings, etc. are tried, in addition to testing the dual-frequency towfish option (100 and 500 kHz). Having already sailed the most difficult parts of the course in the relatively rough waters that day, the captain returns to the marina. On the return trip the engineer notes that recreational fishing boats could present an access problem.

16. Plans are made for primary and alternate survey dates. Prior to the survey dates, the engineer, with camera and film, arranges to have the crewman meet him earlier on the morning of the survey to set up the onshore components of the positioning system. Based on a review of the marine forecast on the afternoon before the chosen date, the decision is made to go ahead.

17. Weather conditions on the survey date include a moderate steady wind, a 5-ft swell, and 2-ft waves. Although the wave/swell conditions are at the borderline of acceptability for this shallow-water inspection, all other conditions are good and the captain feels that the agreed-upon course can be navigated. The crabwise motion of the boat due to wind poses no problem, since the electronic positioning will be used and the crewman will be noting towfish position relative to the boat.

18. The first pass parallel to the breakwater is carried out at a steady speed of 5 knots in water averaging 35 ft in depth; the towfish is "flying" at an average altitude of 20 ft above the bottom. The 100-kHz frequency with a range selection of 100 meters has been selected for the initial pass. The above-water portion of the breakwater is at an average distance of 150 ft from the boat. Well within the backscatter limit at this range, there is good resolution with the 100-kHz frequency that tolerates the wave-induced towfish motion better than the 500-kHz frequency.

19. While preparing to make a second parallel pass to look up at the structure from the relatively low towfish altitude of 10 ft (above the bottom)

to get good definition of the toe, a pair of fishing boats arrive. After carefully explaining the situation to their captains over the VHF radio, they agree to give way, allowing a straight survey line. A third pass is made flying the fish at 30 ft (above the bottom). This position allows the towfish to look down the slope of the breakwater to help distinguish breaks in slope of the armor layer due to settling or loss of units. Based on review of imagery from the earlier passes, several locations showing obvious inconsistencies are noted and the above-water sections are photographed during the third run for position reference. A decision is made to have divers sent to more closely inspect these spots as soon as possible.

Limitations and Problems; Recommended Practices

20. For the most part, the desirable aspects of equipment and operating procedures have been highlighted in the prior sections; however, some of the reasoning must be explained. The state-of-the-art digital auto-correcting system has important advantages for coastal engineering applications. First, the need for operator experience has been greatly reduced. Second, there is much greater consistency in the quality of the imagery generated from one survey to the next, since the internal electronics now control much of the knob tweaking. Third, removal of speed variation- and slant range-induced distortion aids greatly in interpretation of the imagery.

21. Speed variation correction consists of matching the advance speed of the display (speed at which the chart paper passes under the printing mechanism) to the actual over-the-bottom speed of the towfish. The use of position-fixing equipment is highly recommended. With currently available equipment and careful attention to the towfish position relative to the onboard antenna, pinpointing positions of features can be done with relative accuracy. Also, over-the-bottom speed of the towfish can be supplied to the speed-correcting unit as an alternative to the towed speed log data. Slant-range correction consists of using the towfish altitude to convert the actual straight-line distance between the transducer and the target to the corresponding horizontal distance between a point on the seabed directly below the tow fish and the target (Figure 2). Although these corrections are helpful in interpreting the sonograph, there are several distortions not compensated for by the currently available systems or introduced by the correction process.

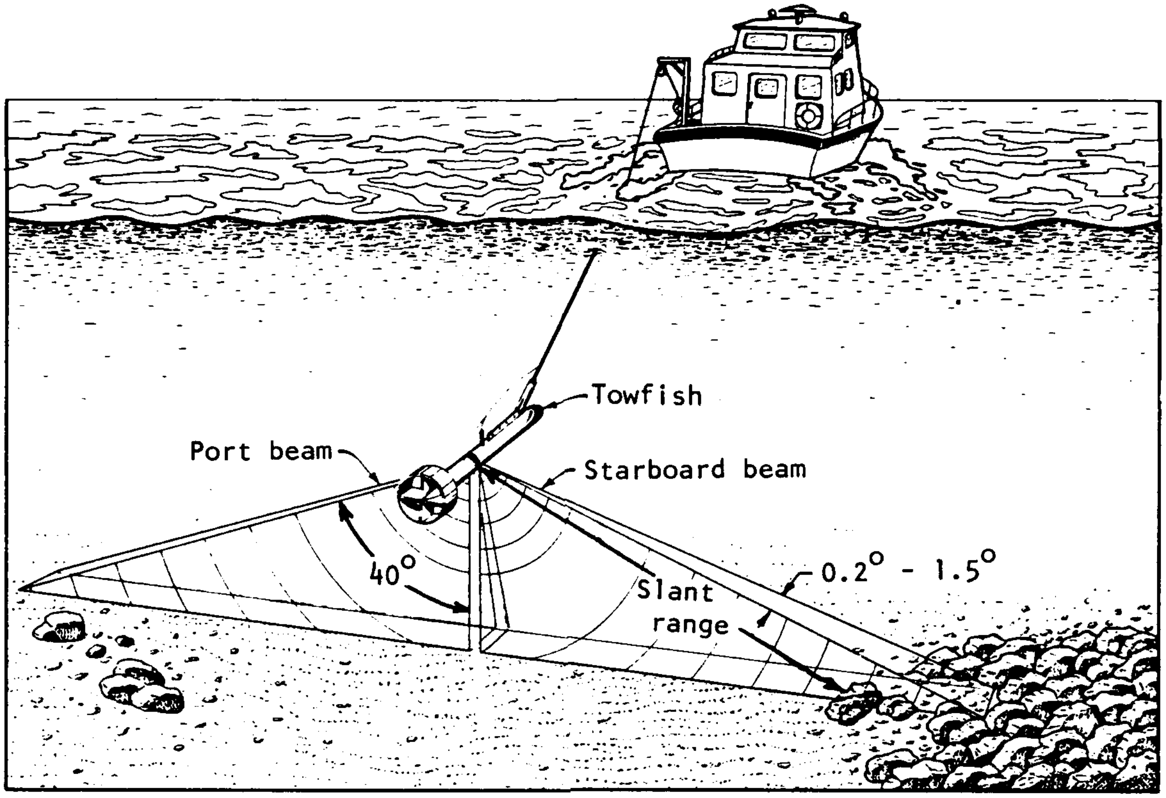


Figure 2. Side scan sonar in operation

22. Essentially, the slant-range correction assumes a flat seabed with low target relief. Thus, any violation of this assumption introduces some distortion in the plotted horizontal position (range) of targets, notably sloping or undulating bottom and projecting targets. An example pertinent to coastal applications is a sloped breakwater face on a flat bottom. The breakwater face will be plotted steeper than it really is, image-corrected or not.

23. An optional digital data recorder may be useful to redisplay the image at the office, for duplicate copies or for experimenting with different enhancement or correction techniques.

24. The key aspects of a desirable survey boat relate to providing a protected, convenient, and electro-mechanical noise-free environment for the control unit and to positioning the towfish so that image quality and usefulness are maximized. The vessel must follow a prescribed course at relatively low speed while transmitting a minimum of yaw, pitch, and roll motions to the towfish. These objectives can be difficult to achieve in shallow-water conditions, unlike in deep water where the long length of the tow cable helps damp out transmitted motions. Erratic motion of the towfish will decrease the

resolution of the imagery as well as decrease the accuracy of the various automatic corrections. Also, the captain should remember that the towfish will tend to fly deeper for a given cable length at low speeds. When turning, care must be taken so that the fish will not hit bottom and the cable will not become fouled in the propellers. Although slower tow speeds are desirable in that they allow more time to look at a point target, low speed in choppy conditions may cause excessive boat motions. In addition, time required to complete the survey must be considered, since periods of low currents are generally short in the vicinity of coastal structures.

25. Currents are undesirable because the towfish will tend to orient itself in line with the current, possibly not desirable from a scanning angle standpoint. If a speed log is being used, there may be an error in the speed correction since the log may not give the true over-the-bottom speed. However, it should be pointed out that in zones where currents are unavoidable, at least some qualitatively useful data can be obtained, whereas the same conditions might be unsafe for divers.

26. In calm conditions it may be possible to get into close range and use the higher resolution 500-kHz frequency for sharp, detailed images, particularly of features selected for closer scrutiny from a screening run at 100-kHz. Keep in mind that, generally, as frequency increases, usable range decreases, and as range increases, resolution decreases. The transmission of acoustic energy in water is also affected by conditions of turbidity, salinity, velocity, and thermal nonuniformities. Speed of acoustic energy travel can differ from that assumed by the manufacturer in calibrating the unit, and discontinuities due to such conditions can cause refraction and/or reflection of pulses. Range of operation can be limited by turbid conditions due to a reduced backscatter limit (the range at which the system is unable to discriminate between targets and background noise). None of the errors introduced by nonuniformities can be removed from the data with current equipment; therefore, it is best to schedule around conditions where there is strong stratification, if possible. Keeping the towfish out of the wake is important for an additional reason: air entrained in the water column will interfere with the transmission of the acoustic pulses. The same interference occurs in wave-breaking zones on the structure. For this reason, surveying at high tide on calm days is recommended.

Rules of Thumb

27. Details and rules of thumb for consideration to aid in SSS operation include:

a. Environmental limitations:

(1) Wave heights less than 5 ft at shallow-water (under 100-ft depth) sites; in depths less than 20 ft, near calm required.

(2) Survey during high water slack for maximum depth, minimum currents.

b. Deployment method:

(1) Tow point on center line at bow, with 10- to 20-ft boom extension.

(2) Midships tow point preferable in special circumstances.

c. Tow speed is a minimum of 1 knot, typically 2 to 4 knots.

d. Towfish depth:

(1) One-half to two-thirds of average depth at shallow-water sites (single pass).

(2) 10 percent of range setting in deep water, noncorrecting SSS system.

(3) 15 to 40 percent of range in deep water, auto-correcting SSS system.

e. Frequency:

(1) 100 kHz for reconnaissance, screening, or rough-water survey.

(2) 500 kHz for close range, detailed inspection.

f. Range:

(1) 25 m or greater, depending on safe operating distance (100 kHz).

(2) 50 m, 75 m, detailed inspection (500 kHz).

PART IV: DATA INTERPRETATION

28. It is beyond the scope of this report to give a detailed guide to sonograph interpretation; however, it is useful to have some introduction to the subject when considering investing in SSS equipment. Experience plays a primary role in interpretation, more an art than a science at present. Similarities exist between sonographs and other types of remotely sensed images (for example those obtained from side-looking airborne radar); thus many principles of interpretation are held in common. An important aid to interpretation is a familiarity with the area or structure to be surveyed; thus knowledge from local fishermen, annotated plans, etc., is very helpful.

29. As mentioned in the introduction, the high-frequency (ultrasonic) acoustic pulses are emitted in two fan-shaped beams (Figure 2) traveling perpendicularly outward from the towfish and encountering the bottom and its features. The instantaneous area being illuminated (the analogy to light rays is useful for visualization) is long in the across-track direction and narrow in the along-track direction. The angle of incidence is almost zero near the fish and increases with distance out to the sides. The sonograph is created so that a strong returning signal (reflected energy directed at the transducer) results in a dark trace on the display, whereas no returning signal leaves a blank trace, where the shade of the image corresponds to the amount of background noise. Thus, there is a similarity to a black and white photographic negative of a scene lit by a pair of spotlights moving forward along the track.

30. The factors determining the strength of signal returns are (a) acoustic reflectivity of the target; (b) orientation or slope of the reflecting surface with respect to the impinging pulses; and (c) distance separating the target from the transducer. Acoustic reflectivity of a target (including the seabed) is determined by both the material itself and its surface texture. Examples of good acoustic reflectors are smooth steel and concrete, whereas soft, textured objects, such as seaweed beds, would generally tend to absorb rather than reflect. For bottom materials, gravel has the highest, sand has intermediate, and mud has the lowest reflectivity. Target shapes or orientations that tend to reflect back at the transducer result in strong traces. Consequently, surfaces sloping toward the transducer (such as breakwater faces) can be expected to reflect well relative to surrounding hor-

izontal surfaces. Due to dissipation of energy in pulses with distance traveled, as well as the effects of lower angle of incidence, targets farther from the towfish will give weaker returns. However, the newest systems with a time-variable gain circuit can compensate for the signal dissipation to a large degree.

31. Features are only identifiable on sonographs when they present a contrasting reflectivity to their surroundings. The resulting amount of detail is sensitive to resolution, primarily controlled by frequency, range, and degree of towfish motion in directions other than the straight-line track direction. Discrimination of isolated features is aided by acoustic shadows, although shadowing presents problems in distinguishing nonisolated, irregularly shaped targets. For example, individual armor units usually cannot be distinguished from their neighbors due to shadowing and lack of contrast. Figure 3 shows an example sonograph from a qualitative survey of the rubble-mound breakwater at Crescent City, CA. The following noncomprehensive list gives an idea of what can (sometimes) be seen with SSS:

a. Outline of structure toe (jetties, breakwaters).

b. Isolated displaced armor units.

c. Depressions and mounds (scour holes, spoil piles).

d. Abrupt changes in slopes.

e. Sunken objects, vehicles, debris.

f. Bottom material boundaries (e.g. sand patches on clay bottom).

g. Bottom relief such as sand waves (useful in determining current and transport direction), dredge/anchor/ice marks.

h. Cables, chains, piles.

Vertical structures can be imaged with the towfish in the conventional horizontal deployment position, or it may be beneficial to rotate the fish on one of its axes to view the structure from a different perspective. Since vertical walls are ordinarily used only in coastal environments with very low wave energy, it may also be possible to fix the transducers in a frame or other more stable, controllable configuration (such as the truck-mounted crane deployment mentioned earlier). However, due to the very low angle of incidence for vertical walls and their other reflectivity characteristics, returns can be so intense that discrimination of features is difficult. When they are present in a site being surveyed, if contrast is adjusted to permit discrimination of less reflective features, there can be a ghost image

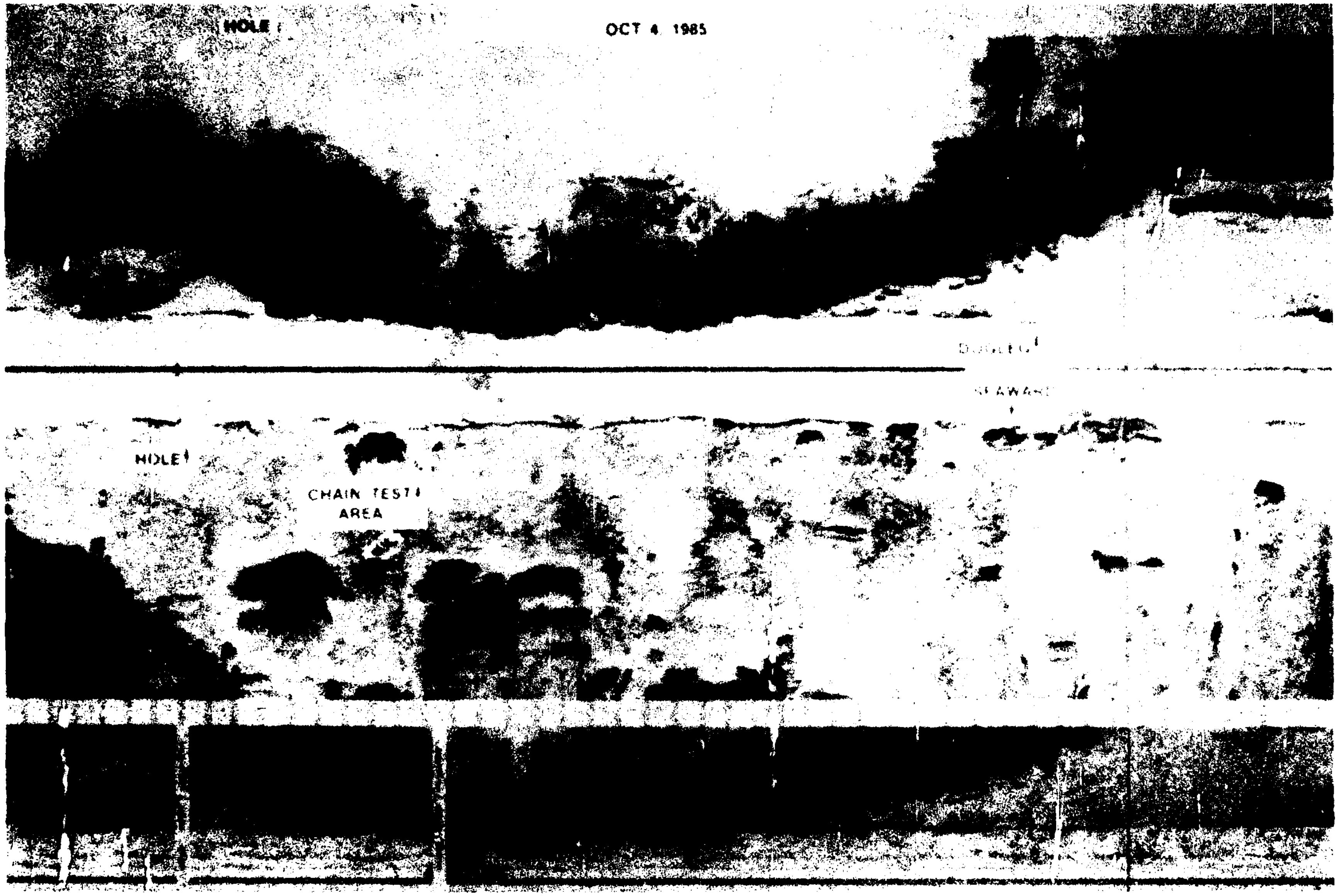


Figure 3. Portion of sonograph from image-correcting digital SSS (EG&G Model 260)

produced on the trace from the transducer on the opposite side of the fish from the wall (this is also referred to as cross talk).

32. Circular-shaped vertical features such as steel sheet pile cells can result in image artifacts called diffraction hyperbolae. Often, cavities and cracks can be recognized as dark traces perpendicular to the otherwise unbroken dark/light linear boundary resulting from the wall face. Cavities of rectangular shape may cause points of high reflectance due to the "corner reflector" phenomenon, i.e., returns are reflected directly at the transducer over a range of incident angles. Refer to Morang (1987)* for a more detailed discussion and examples of these phenomena.

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* Morang, A. W. 1987. "Side-Scan Sonar Investigation of Breakwaters at Calumet and Burns Harbors on Southern Lake Michigan," Miscellaneous Paper CERC-87-20, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

PART V: POTENTIAL COASTAL ENGINEERING APPLICATIONS

33. Although SSS has been used in a wide diversity of coastal engineering problems, there are many untested applications remaining to be discovered. With present systems, further expansion of qualitative coastal structure inspection uses can be expected, particularly in high-turbidity environments with large and irregularly shaped structures. The use of unconventional mountings and platforms for the transducer in port and harbor structure inspections is an application likely to grow. Similarly, use of ROV's as platforms has potential. A natural role for SSS is as a rapid overview tool, pinpointing problem areas to be examined in detail by divers or ROV's. As techniques and technology continue to improve, especially those permitting a more quantitatively accurate image to be obtained (such as scanning sonars), the uses of these acoustic tools will increase in quantitative applications. These applications include bottom change monitoring for modeling efforts and construction related surveying.

PART VI: EVALUATION RESULTS FOR AVAILABLE EQUIPMENT

Introduction

34. Brief evaluations for five commercially available sonar devices are given in paragraphs 35 through 44. Keep in mind that the market and the technology are in flux. It is important to research the currently available systems before buying equipment, since the following is very brief and will soon be out of date.

EG&G Model 260 Image Correcting Digital SSS System

35. The EC&G Model 260 is the state-of-the-art SSS. The authors have direct experience using this system for typical coastal applications of the type discussed in this report. The significant features of this system are:

- a. Automatic corrections for gain, speed variation, and slant range.
- b. Compact and lightweight control unit.
- c. High image-quality dry paper display.
- d. Switchable towfish frequency (100 or 500 Khz) from onboard unit.
- e. Survey speeds up to 12.7 knots (fastest available).
- f. Power from AC or optional DC; convenient to use battery power.
- g. Flexible for adding input from positioning system, etc.
- h. Digital cartridge-type data recorder available as an option.

36. This equipment is a versatile tool for use in the coastal engineering field and is the authors' preferred system.

KLEIN Model 590 Digital SSS

37. The Klein Model 590 is the newest design from KLEIN incorporating digital and microprocessor technology. The authors have used KLEIN SSS systems for a number of years, although this newest model has been seen only in a trade show setting. KLEIN equipment is more modular in format than the EG&G system described in paragraphs 35 and 36; thus it is possible to

configure a system including automatic corrections for gain, speed variation, and slant range by purchasing the necessary options. Other features available include:

- a. Digitally controlled dry paper display.
- b. User friendly operating panel with many presets and battery backup of memorized settings (in case of power interruption).
- c. Capable of simultaneous 100- and 500-kHz side scan and 3.5-kHz subbottom profiler data collection.
- d. Flexible for adding other processing/convenience modules.

38. The modularity of the KLEIN equipment can be an advantage or a liability, depending on the user's perspective; from the authors' viewpoint it is somewhat cumbersome for coastal engineering work. Also, the analog tape data recording option is less convenient and reliable than the digital cartridge recorder available for the EG&G system. However, this system should perform in the manner of all previous KLEIN instruments and can be used in the coastal environment.

KLEIN Models 520 and 530 Analog SSS

39. The Klein Models 520 and 530 SSS have been manufactured since 1978. The Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, owns a Model 530 and has used it successfully on several coastal structure inspection projects and continues to use it. A number of US Army Engineer Districts also own these SSS models. The primary limitation of the Models 520 and 530 SSS is the operator skill required to adjust the approximately 24 knobs associated with variable gain, print intensity, etc. In addition to being considerably more difficult to tune initially, the instrument requires frequent adjustment to obtain the optimum image, particularly when operating in the changing environment near coastal structures.

40. For occasional users of SSS, it is probably not cost effective to replace the older analog models such as the 520 and 530 with the new digital, self-tuning SSS. Whenever a competent operator is available, the tuning difficulties, wet paper, a heavy and bulky receiver, and less precise analog recording capabilities can probably be overlooked. Only those districts considering a new SSS or expecting to perform a significant amount of detailed inspections should invest in a digital SSS.

MESOTECH Model 971 Scanning Sonar

41. The MESOTECH Model 971 does not fit the description of the SSS given at the beginning of this report. A Model 971 system consists of a motorized scanning transducer head, a "black box" processing unit, and a CRT color video display unit (this can be connected to a video recorder by means of an optional adapter). Experience with this system consists of a demonstration performed at Crescent City, CA, where there was an 8-ft swell with 2-ft waves. Features of the Model 971 system include:

- a. Flexible mounting configuration and scanning scheme.
- b. A 675-kHz frequency transducer with a beamwidth of 1.7 by 60 deg; other beam patterns available include 1.7 by 30 deg and 1.7 deg (conical).
- c. Lightweight, compact transducer head.
- d. High-resolution display.
- e. Various processing/display modes.

42. In the conditions tested, the system was found to be of no use for the purposes of coastal engineering structure inspection; however, there may be useful applications in sheltered environments or when mounted on an ROV. Also, the contrast and gain were not adjustable for easy viewing. The system may be helpful for profiling applications (where the bottom profile for a sector under the transducer is scanned in a sweep, a configuration appropriate for channel dredging-related surveys).

ULVERTECH Dual Scanning Sonar Profiler

43. The ULVERTECH system also should not be classified as a conventional SSS. This system consists of two separate motorized scanning heads, an electronics box to be mounted underwater, a control unit, and a display/recorder unit. The configuration was tested in a demonstration at the Columbus Lock and Dam on the Tenn-Tom Inland Waterway. Principal features of the system are:

- a. Flexible mounting and scanning.
- b. A 1-MHz frequency transducer with a 1-deg conical beam.
- c. Automatic combination of the data of two scanners to display continuous bottom profile.

d. Flexible for input of positioning data or further processing.

e. Standard CRT video monitor can be used for display.

44. The system worked well under the calm conditions of the demonstration, but coastal uses would be limited to very sheltered waters. Resolution is excellent, but consequently, range is limited to 40 m, and scanning, hence time required to complete a survey, is slow. Applications of this system are essentially the same as those listed for the MESOTECH system.

PART VII: SUMMARY

45. In spite of computerized digital image processing available in off-the-shelf SSS systems, even under the best of environmental and site conditions, SSS has limited quantitative application in coastal engineering. Information on structure slopes, condition of individual armor units, and percent of units displaced (to name a few examples) is not currently measurable in a repeatable, quantitative way. However, the semiquantitative sonograph record can be very informative, particularly to someone familiar with the structure or feature being viewed. Also, a strong point for the SSS is its ability to collect information in murky water while being deployed at a safe distance from the structure. Thus, it is a safer and, in many cases, superior alternative to visual inspection by divers. It is clear that SSS is a valuable tool for coastal engineering, with uses continuing to multiply as technology and experience improve. Further ingenious applications are limited only by our imaginations.

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Product literature from the following manufacturers:

EG&G Environmental Equipment, 151 Bear Hill Road, Waltham, MA.

Klein Associates, Inc., Undersea Search and Survey, Klein Dr., Salem, NH.

Mesotech Systems Ltd., 2830 Huntington Place, Port Coquitlam, BC, Canada.

Ulvertech America, Inc., 9 Birchwood Dr., PO Box 406, Derry, NH.